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Technical Memorandum 33-332

Venus/Mercury Swingby with Venus Capsule

Preliminary Science Objectives and Experiments for Use in Advanced Mission Studies

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I. Introduction

This document describes several possible scientific objectives with their supporting experiments and also provides the scientific information for a preliminary mission-study of a *Mariner*-type spacecraft to be flown in a swingby trajectory to the planet Mercury via a close encounter with the planet Venus during the 1970–1973 period. The study was prepared as a joint effort by the Future Projects Office and Space Sciences Division of the Jet Propulsion Laboratory.

It has been proposed by Minovitch (Ref. 1) and Hunter (Ref. 2) that trajectories using the gravitational perturbations of Venus can be used to achieve a lower launch velocity mission to Mercury. For example, an analysis of the 1970 opportunity by Cutting and Sturms (Ref. 3) suggests a distance of closest approach to the surface of Venus, depending on the time of launch within the 30-day launch period studied, ranging from 1500 to 3300 km, with the total flight time to Mercury ranging from 158 to 182 days. The communication distance at Mercury encounter for this opportunity will be about 175,000,000 km. Similar calculations have been made for other opportunities in the 1970s, and they suggest flyby distances from both Venus and Mercury that are very favorable for scientific observations. Further, these trajectories provide an opportunity for an occultation experiment on Venus, and under limited circumstances, on Mercury and the outer portion of the Solar Corona.

The launch vehicle assumed for this mission study will possess at least the capabilities of an *Atlas/Centaur:* a *Mariner*-type spacecraft weighing upwards from 1300 lb for the 1970 opportunity, and 1000 lb for the 1973 opportunity. In the event an improved *Atlas/Centaur* launch vehicle is available for the 1973 opportunity, the spacecraft weight will increase to approximately 1360 lb. The most reasonable opportunity in the 1970–80 decade for a Venus/Mercury swingby mission appears to be in 1973 with launch between October 20 and November 11, and for a fixed Venus arrival date of February 5, 1974. It is felt that a 1360-lb spacecraft can accommodate approximately 250 lb of science instrumentation plus a 200-lb instrumented capsule for atmospheric entry at Venus.

A Venus/Mercury swingby-type mission appears to be very desirable and practicable from the scientific point of view as it offers an unusual opportunity in an early mission to visit two planets and obtain data relating to a variety of scientific problems.

II. The Planet Venus

Knowledge of the solid body of the planet Venus (Ref. 4) is presently limited by the cloud deck which completely obscures the underlying surface in visual wavelengths. Telescopic and photographic observations do not reveal any sharp planetary features. Some indistinct features and occasional dark and light spots have been recorded and attributed to surface markings, although they generally lack reproducibility in position and shape in sequential observations. Infrared photographs show no details; however, ultraviolet photographs show bands and other atmospheric markings that seem to be a normal although changing feature of the visible disk of the planet. These observations and the high visual albedo of the planet certainly suggest a dense cloud cover that permanently obscures the solid surface of Venus.

Between February and August 1964, extensive radar observations were made of Venus, employing one of the 85-ft parabolic antennas at the NASA/JPL Deep Space Instrumentation Facility located at Goldstone, California. Carpenter's analysis of these data indicates that Venus has a sidereal rotation period of 250 days retrograde (243 to 254 days) with the spin-axis oriented within 20 deg of the orbit pole (Ref. 5 and 6). The observations further substantiate the existence of physiographic features on the planetary surface.

The observed radius of Venus is usually given as about 6200 km, but the radius to the solid surface is not known because of uncertainty about the height of the layers of the atmosphere that are taken as the outer surface. Allowing 60 km for this height leads to the value 6140 km. The current value for the mass of Venus was calculated from perturbations on the orbit of *Mariner II,* and is given as 4.86954×10^{27} g. These figures give a density of approximately 5 g/cm^3, but because the true radius of the planet is not known, estimates of the density of Venus vary from 4.8 to 5.4 g/cm^3.

A range of models of the planet can be constructed within the limitation imposed by the visual radius, and all of these require Venus to have a liquid core if the planet is similar in construction to the Earth. The moment of inertia of these models can be found, but observation supplies no serious check on the values because of the extremely slow rotation.

The probability of melting in Venus suggests that volcanism has occurred and that constructive land forms have been so produced. The complexity of a Venusian crust is probably a function of the kinds and intensities of erosive and depositional mechanisms operative. If liquid water is currently absent from the surface of Venus, the present relief would be a function of the rate of wind erosion versus rates of crustal deformation and volcanism. If the atmospheric circulation is very great, the planetary surface will approach a vast plain overlain by a dust-filled atmosphere.

It should be emphasized, however, that current conditions on the surface of Venus may be vastly different from conditions in the past. Urey (Ref. 7), as early as 1952, first pointed out that H_2O is by far the most cosmically abundant oxidizing agent and that much water necessarily must have existed on Venus in the past in order to provide sufficient oxygen for CO_2. Photo-disassociation of H_2O, oxidization of carbonaceous molecules, and escape of hydrogen were the probable events in the depletion of water on Venus. The more rapid depletion of water from Venus than from the Earth may have been due to its closer proximity to the Sun.

If the illuminated side of Venus has a temperature of nearly 700°K and surface water pressure is negligible, surface conditions are truly in the metamorphic realm. Surface phase assemblages formed in the past may have been transformed to new assemblages that are stable under the existing environment. In general, many hydrous phases would have either partly dehydrated, or have converted to new anhydrous phases at 700°K, zero water pressure and 50 atm of total pressure.

The atmosphere of Venus is optically thick and full of particulate matter (clouds). Neither theory nor observation are yet in a state sufficient to provide a secure picture of the atmosphere near the cloud tops, to say nothing about the deeper atmosphere. We do know that it contains CO_2. Kuiper and others have identified isotopic bands due to $^{13}CO_2$ and $^{12}C^{18}O^{16}O$, as well as the normal CO_2 with ^{12}C and ^{16}O (Ref. 8). At least some CO must be present as a disassociation product of CO_2, but the spectroscopic identification by Sinton in 1962 at 2.35μ must be considered tentative since it was "way down in the noise" (Ref. 9).

In 1959, Strong reported the possible existence of H_2O on the planet Venus based on balloon-flight observations by Moore and Ross (Ref. 10). In 1963, Dollfus reported 100μ of water vapor, based on observations of the 1.4μ band from Jungfraujoch (Ref. 11). In 1964, Bottema, Plummer, and Strong flew an improved (and this time unmanned) balloon with a spectrograph using the so-called Benedictine (multiple) slits; they confirmed the result reported in 1959 for the 1.13μ H_2O band. They found 30–125μ of H_2O, the exact amount depending upon the unknown "base level" pressure (Ref. 12). The repeated attempts made by Spinrad to detect indications of water vapor at λ8180, using both the existing spectra and some new spectra taken with the very fine 120-in. reflector at the Lick Observatory at a dispersion 1.8 Å/mm, have utterly failed. Spinrad's[1] absolute upper limit is 70μ of H_2O. This is a significant clue to the Venus atmospheric structure, however, for it implies a relatively high cloud level atmospheric pressure—say in excess of 600 mbar.

In 1963, Prokofyev and Petrova reported the discovery of O_2 on Venus from studies of the α-band at λ6300 (Ref. 14); however, other observations by Spinrad and Richardson dispute this discovery (Ref. 15).

Nitrogen is also a major question. In 1954, Kozyrev reported auroral-type emission features which he attributed to N_2 and N_2^+ in the atmosphere of Venus (Ref. 16). In 1959, Newkirk reported a partial confirmation and partial disagreement with Kozyrev's result (Ref. 17). In 1961, Weinberg and Newkirk were unable to confirm Newkirk's (or Kozyrev's) earlier work (Ref. 18).

It might be expected that some argon might be found in the Venus atmosphere. There is no easy way to verify this from the surface of the Earth since argon has no low-excitation absorption spectrum. Other substances have been suggested from time to time as possible constituents of the Venus atmosphere. None has been identified spectroscopically.

Only CO_2 and its isotopes are absolutely accepted by all observers as being present in the atmosphere of Venus. Yet independent studies by Kaplan (Ref. 19), Spinrad (Ref. 20), and Chamberlain (Ref. 21) all agree that CO_2 is a relatively minor constituent of the Venus atmosphere, comprising perhaps a few percent by mass. It is usually assumed that the remainder of the atmosphere is N_2 for want of any better idea.

The brightness temperature of Venus at microwave wavelengths is quite high. A number of observers have tried to explain these brightness temperatures as something other than a true surface temperature. The *Mariner II* observations of limb-darkening made this task much more difficult, and the 1965 paper of Clark and Kuz'min on the polarization across the disk of Venus at 10.6 cm made it virtually impossible, insisting as it does that the radiation comes from a compact surface (Ref. 22). The temperatures at 8–14μ are much lower; most measurements give about 234°K and appear to refer to a level in the vicinity of the cloud tops (Ref. 23).

The microwave data for Venus suggest a thermal gradient of some 450°K between the clouds and surface of Venus (Ref. 24). The temperature lapse rate is, at most, adiabatic and possibly sub-adiabatic. This implies a very thick atmosphere and a very high surface pressure at the cloud deck, exact atmospheric composition, etc. It also raises the question of how the elevated surface temperatures are maintained. What causes the tremendous atmospheric opacity? Pressure broadened CO_2, CO_2 and H_2O, CO_2 plus an unknown absorber, the clouds (particulate matter), and various combinations of these have been suggested as sources of the opacity. Actually neither theory nor observations have been adequate to deal with the problem, although at the moment, theory is perhaps advanced over observation.

From the foregoing section, it is fairly obvious that we need to acquire some very fundamental facts about Venus. The initial step is to develop a model of Venus as it is today. We first must determine the atmospheric and surface temperature and its variations with time and location, the atmospheric pressure and composition, the rotational period of the planet and its axial orientation, wind conditions, and the amount of relief on the Venusian surface. These facts would allow us to understand the planet as it is today.

Furthermore, gross body parameters of Venus must be measured so that the present configuration and internal structure of the planet can be understood. Measurements of radii, moments of inertia, the surface heat flux, and the strength of the magnetic field are needed.

III. The Planet Mercury

Mercury is the smallest of the nine planets of our Solar System, being intermediate in size between the Earth's Moon and Mars. Its exact diameter is not at all well determined. Results by reputable workers have varied all the way from W. Rabe's 7.″09 at 1 AU (Ref. 25) to a result of Lundmark quoted by Urey of 5.″7 (Ref. 26). The "American Ephemeris and Nautical Almanac" uses Le Verrier's result of 1843, namely 6.″68 (Ref. 27). Dollfus measured 6.″45, by using a birefringent double-image

[1]In Ref. 13 and in H. Spinrad 1965 private communication.

micrometer during the 1953 transit (Ref. 28). The collected results of eleven observers of the 1960 transit was 6.″67 (Ref. 29), while a separate group has reported 6.″84 (Ref. 30). It seems likely that the value is indeed in the vicinity of 6.″8 (or 4950 km), but with a probable error of at least ±5%.

All telescopic studies of Mercury are difficult to make, since the angular separation of Mercury and the Sun never exceeds 28 deg, and reaches that only at an aphelic elongation of the planet. As a result, studies must be made in full daylight, or in twilight with Mercury very near the horizon. Furthermore, Mercury is an intrinsically small object, as noted above, with a maximum apparent diameter at an aphelic inferior conjunction of 13 arc sec, and, indeed, Mercury is virtually unobservable at such times since the hemisphere then facing us is unilluminated, and the planet is very close to the Sun.

The conventionally adopted mass of Mercury was initially determined by Newcomb from perturbations in the motions of the inner planets. Duncombe, who has rediscussed Newcomb's data, suggests a value of (0.3379 ± 0.0260) × 10^{27} g (Ref. 31). Brouwer, from the secular perturbations of Mercury and the Earth, suggests a value of (0.3066 ± 0.0169) × 10^{27} g (Ref. 31). Rabe, from the perturbations of Eros by Mercury, suggests a value of (0.3246 ± 0.0023) × 10^{27} g (Ref. 32). The maximum value implied from the probable errors of these results is (0.3639 × 10^{27} g) by Duncombe, and the minimum value is (0.2897 × 10^{27} g) by Brouwer. Values found for the mass evidently range from ±10% of their mean.

If we assume a radius for Mercury of 2475 km, and a mass of 0.32304 × 10^{27} g, which is the mean of the three results given above, then the calculated mean density of the planet is 5.1 g/cm^3. This is certainly anomalous, for it is much higher than for the more massive Mars, and it even exceeds the value determined for Venus from perturbations on the orbit of *Mariner II*. It should be observed however, that the mass is liable to an error of ±10% and the radius is liable to an error of ±5%; therefore, the mean density could be in error as much as ±25%. Considering this large probable error, the mean density of Mercury could be as high as 6.2 g/cm^3 or as low as 3.7 g/cm^3.

Until very recently, Mercury's rotation period was believed to be synchronous with its orbital period; however, radar measurements at Arecibo by Pettengill and Dyce indicate that the planet has a very slow direct rotation (Ref. 33). This direct rotation has a period of about 59 days, and indeed this is not too surprising theoretically (Ref. 34 and 35).

The equilibrium temperature of an insulated black body always keeping the same face toward the Sun would be 633°K (Ref. 36 and 37). Mercury rotates so slowly and has such a low albedo that one would expect to measure temperatures not too different from this figure with a thermometer stuck in the "soil" of Mercury. The orbit of Mercury has considerable eccentricity (0.2), so one would expect appreciably higher temperatures when Mercury is near perihelion and lower ones near aphelion. Actual radiometric temperatures in the 8–14μ region of the spectrum give brightness temperatures of 610°K at mean distance, and 685°K at perihelion near the subsolar point.

The first microwave measurements of the brightness temperature of Mercury were reported in 1962. Howard et al. (Ref. 38) reported a value of 400°K (with a probable error of perhaps 100°K) for the mean temperature of the disk at 3.45 and 3.75 cm measured near greatest elongation. They reported a very high subsolar point temperature based upon the assumption that the dark side of the planet was effectively at zero temperature, an assumption that is no longer valid now that Mercury is known to rotate. Actually, these data are not inconsistent with the infrared data when the rotation of Mercury and probable errors of observation are considered. Kellermann, working at 11.3 cm, studied the phase effect on brightness temperature and found virtually no effect; only a constant temperature of about 300°K, day or night (Ref. 39). Epstein, working at 3.4 mm, has found temperatures around 200°K, again with no phase effect (Ref. 40).

Photometric properties of Mercury, including albedo, color index, and even the polarization curves and phase integral, are very similar to those of the Moon (Ref. 41 and 42). The radar reflection is similar to the Moon (Ref. 43). The general appearance of Mercury in a telescope under excellent conditions is like that of the Moon as seen with the naked eye. In spite of these observational difficulties, crude maps of one hemisphere exist (Ref. 44).

A number of attempts to detect an atmosphere on Mercury spectroscopically have been made through the years. Moroz has reported detecting CO_2 on the planet in an amount between 0.3 and 7 g/cm^2 (Ref. 45). Working in the photographic infrared, Spinrad et al. (Ref. 46) were only able to set upper limits on CO_2 (57 m-atm), O_2 (2 m-atm), and H_2O (30μ). These results, they pointed out, were compatible with those of Moroz only if the surface pressure is about 4 mb. Such a high pressure seems incompatible with the polarization measurement of Dollfus which indicates an atmosphere of perhaps only ⅙ of that amount (Ref. 41). These observations are all difficult, and perhaps the problem at present is dominated by observational error, but a contradiction certainly seems to exist.

The best indication is that there exists a very weak atmosphere on Mercury, many of the arguments for this having been summarized by Field.[2] It does not seem likely that it would contain any of the common atoms such as oxygen, nitrogen, carbon and/or their molecules. Most of any atmosphere would have been lost because of the low mass of the planet and the very high surface temperatures. In fact, the surface temperature probably approaches 700°K, the critical temperature for the exospheric escape of the lighter elements. Any atmosphere must consist of the heavier inert gases, emissions from the interior of the planet, and possibly some lighter atoms, molecules, ions, and free radicals in equilibrium with the local interplanetary medium. Because Mercury is now believed to have a slow rotation period, it is not likely that a cold trap exists on one side of the planet. The composition of the tenuous atmosphere of this planet should be measured before it is contaminated by the exhaust of retrorockets.

Both elemental and isotopic analyses would be required to separate the constituents of diverse origins in the atmosphere of Mercury. The amount of argon-40 would be a clue to the extent of degassing of the planet. The amounts of the heaviest rare gases, Kr and Xe, might also allow us to estimate the extent of the original atmosphere of Mercury or the original gas content of this body.

Obvious experiments of promise are all those previously suggested for the Moon, from photography to seismometry, plus experiments designed to measure accurately the simple body properties such as mass and diameter.

Because the physical environment of Mercury is too severe to expect the origin and evolution of life, direct biological test for living organisms would scarcely need to be considered in early studies. However, current theories on the evolution of the solar system suggest that organic compounds may occur on all planets. The detection and identification of organic matter on any planet in the solar system are of interest because of their possible bearing on the origin of life.

[2] Those relating to synchronous rotation are obviously no longer valid (Ref. 47).

IV. Fields and Particles

A. Introduction

A spacecraft trajectory that reaches the orbit of Mercury will give a unique opportunity to extend particles and fields investigations into a new and exciting region of space. In addition, if the spacecraft trajectory near Venus and Mercury is properly chosen, data of very significant and scientific value on these two planets could be obtained.

Monitoring of the interplanetary medium with plasma probes, magnetometers, and solar-particle and cosmic-ray detectors during the interplanetary cruise phase of a Venus/Mercury flyby mission is of interest because of the rarely available opportunity that it would afford to discriminate between temporal variations and spatial variations in the medium by means of widely separated simultaneous measurements, as well as the opportunity that this trajectory presents for investigating the inner part of the interplanetary medium. The extent and shape of plasma clouds or shocks produced by solar flares, and of long-lived plasma streams such as were observed by *Mariner II*, can probably be determined in no other way. Venus-bound spacecraft are particularly appropriate for such studies because the spacecraft is close to the same solar magnetic field line as the Earth for a considerable part of the flight.

The fields and particles investigations near Venus and Mercury would emphasize experiments on the magnetic fields, trapped radiation belts and plasma interactions in the vicinity of these planets. In interplanetary space, energetic particle experiments should be performed in addition to the magnetic field and plasma experiments.

All of these experiments would study the variation of the various experimental parameters as a function of distance from the Sun.

B. Magnetic Field

The general objectives of the magnetometer experiment would be to:

(1) Understand the nature, origin, and the mechanism of production of planetary magnetic fields by the study of two particular examples, namely the fields of Venus and Mercury, and from these data to help determine some properties of the planetary interiors.

(2) Understand the details of the interaction between the solar plasma and the atmosphere or magnetosphere of Venus/Mercury.

(3) Support the particles experiments.

(4) Study the nature of the interplanetary field.

Important questions concerning the interior, the upper atmosphere, and the charged particle environment of Venus/Mercury concern the strength of the magnetic field. Direct measurement of the magnitude, multipole order, and orientation of an intrinsic field could have an important bearing on the validity of the dynamo theory of planetary magnetism and the related question of whether or not Venus and Mercury have a molten core. The spatial extent and temperature of the upper atmosphere depend, in part, on the ability of a planetary field to divert the solar wind. A planetary magnetic field governs the trapping of high-energy charged particles and the extent to which cosmic and solar radiation can penetrate to the surface.

Since *Mariner II* did not detect a planetary magnetic field near Venus, it is desirable to make magnetic measurements much closer to the planet. In fact, magnetic measurements should be carried out as close to Venus as the trajectory will allow, and the same is true for Mercury. If a trajectory is favored that has a distance of closest approach much in excess of about two planetary radii, the most interesting field measurements would likely result if the spacecraft passed through the magnetic tail region near the equator on the side opposite the Sun.

C. Plasma

The properties of planetary magnetic fields are intimately related to the nature of the interaction between the planet and the solar wind. In the case of Venus the nature of the interaction between the planet and the solar plasma was left completely undetermined by the *Mariner II* plasma experiment, but it could be investigated by a spacecraft that passes considerably closer to the planet or penetrates the conical region where the Sun-planet-probe angle is greater than approximately 140 deg. If the magnetic moment of Venus is as high as 1% of that of the Earth, or roughly an order of magnitude less than the upper limit inferred from the *Mariner II* results, we would still expect to see a bow shock and a transition region in the plasma similar to that around the Earth's magnetosphere. If the moment is still an order of magnitude smaller, the incoming solar wind may be simply absorbed by the atmosphere, producing no shock and no transition region but only a narrow cylindrical cavity in the plasma behind the planet. So many unexplained phenomena have been observed in our own magnetosphere that attempts to predict the nature of the Venus-plasma interaction are futile.

In the case of Mercury, its small size, slow rotation rate, and sparse atmosphere suggest that its interaction with the solar wind will probably not differ from that of the Moon.

If the solar wind is able to make a direct encounter with the atmosphere of either planet, then auroral emissions will be produced, either uniformly over most of the sunlit hemisphere if the magnetic field is truly negligible, or in localized regions if it is not. A knowledge of the incident solar-wind flux and energy, obtained from a plasma spectrometer, would assist the interpretation of ultraviolet spectral measurements of these emissions.

The study of the charged particles that make up the interplanetary plasma proper, and the study of the magnetic fields that are associated with it, because of the inherent nature of the plasma physics, are really inseparable parts of the same problem. The two main goals in studying the interplanetary plasma are the investigation of the physical processes in the solar corona and of the basic plasma physics of the interplanetary medium. For the former, we shall wish to measure the intensity, extent, chemical composition, and temporal variations of solar-plasma streams, and to identify their sources. Measurements at all heliocentric latitudes and longitudes will eventually be required. For the latter, we shall look for interactions of the plasma with magnetic fields (both planetary and interplanetary), with solid bodies, with comet tails, and with other clouds of plasma. Wave motion and plasma instabilities will also be of interest. The position and nature of the transition between "supersonic" and "subsonic" flow in the solar wind, and the phenomena occurring at the boundary between the solar and galactic fields, should be investigated. Other questions associated with the physics of the plasmas are the source of the Van Allen belt particles, the nature of the mechanism of their injection into the magnetosphere, and the detailed nature of geomagnetic disturbances.

D. Trapped Radiation

It is well known that the *Mariner II* trapped-radiation experiment found no trace of radiation belts near Venus. For this reason, as presented in the discussion on planetary plasmas, any trapped-radiation experiment would require either that the spacecraft pass much closer to Venus than did *Mariner II* (41,000 km from the planet's center), or at least penetrate the region where the Sun-planet-probe angle is greater than 140 deg. Since Mercury seems to be a body much like the Moon or Mars, with a very weak, if any, magnetic field, the trajectory should be chosen to pass through the tail of the planet as close to the planet as possible. A trajectory that travelled along the tail for a considerable distance would be preferable. The reason for choosing such a trajectory is that, with the expected weak field, the field boundary on the sub-solar side of the planet would be so close to the planetary surface that the spacecraft would most likely not pass near enough to the planet to detect it.

Obviously the correlation of the trapped particle data with the magnetometer and plasma data would be of great interest. The instrumentation for the trapped radiation experiment would also yield valuable data during interplanetary cruise.

The general scientific purpose of the experiment would be to:

(1) Search for magnetically-trapped particles in the vicinity of Venus/Mercury and, if found, make preliminary determinations of their distribution in space, their energy spectra, and their identities.

(2) Monitor the occurrence of solar cosmic rays and energetic electrons in interplanetary space and study their angular distribution, energy spectra, and time histories.

The scientific problems concerning which data of interest could be obtained are:

(1) Magnitude and orientation of the magnetic moment of Venus/Mercury.

(2) Radial extent of the atmosphere of Venus/Mercury.

(3) Delineation of the possibilities for aurorae and magnetic storms on Venus/Mercury.

(4) Interaction of the solar plasma with the magnetosphere, if any, of Venus/Mercury.

(5) Relationship between solar phenomena and emission of energetic particles.

(6) Propagation of charged particles in interplanetary space.

(7) Relationship of the occurrence of energetic particles in interplanetary space to solar and geophysical effects.

E. Galactic Cosmic Rays

In recent years, it has become clear that the cosmic rays that approach the Earth are not a truly representative sample of those that exist in interstellar space. Thus, the major problems of modern cosmic ray research are:

(1) What are the flux, energy spectrum, composition, and anisotropy of the interstellar cosmic rays?

(2) What are the nature and the location of the modulating mechanisms that alter the cosmic ray fluxes at the Earth in response to solar flares and to the general level of solar activity?

Since the Earth's magnetic field and atmosphere blur our observations of the galactic cosmic rays, any spacecraft that goes beyond the magnetosphere provides an excellent opportunity for studying these rays. In general, the parameters of interest are flux, energy spectrum, directional spectrum, composition and time variations. The particular value for these studies of a Venus/Mercury spacecraft, which approaches so near the Sun, is to study the spatial variations of the above parameters. Therefore, it is almost a necessity that, while the Venus/Mercury probe is flying, there be a near-Earth probe with similar instrumentation, preferably outside the magnetopause, to perform control experiments.

We know that the magnitude of the galactic flux is inversely related to solar activity. Since one could not reasonably expect the flux in deep interstellar space to vary with the solar cycle, there must, at least at solar maximum, be a space gradient as one travels radially outward from the Sun. Study of the nature at the gradient might produce information on the mechanism that modulates the galactic flux. A close-in probe, such as a Venus/Mercury probe, would be a logical vehicle for searching for such a gradient. Such missions should be carried out near both the maximum and the minimum of the solar activity cycle.

F. Solar Particles

The same parameters that are of interest for galactic cosmic rays should also be measured for solar charged particles. Much has been said about these particles and many measurements have been made, but a number of important questions remain essentially unanswered. The answers to these questions are important not only for understanding the nature of the particles themselves, but also for an improved model of a typical star such as the

Sun, and of the interplanetary magnetic field. Typical questions are:

(1) What is the nature of the flares that produce these particles?

(2) What acceleration mechanism produces the observed energy spectra?

(3) How are the particles stored and propagated through interplanetary space?

(4) What is the spatial dependence of a solar-proton event?

(5) How do these particles interact with planetary atmospheres and magnetic fields?

When investigating solar-charged particles, it is particularly important to have a similarly instrumented probe near the Earth during the Venus/Mercury flight. This is true because the study of the propagation of these particles through the interplanetary medium is a problem of prime importance.

The proximity to the Sun of a probe at the orbit of Mercury would make an experiment to detect fast solar neutrons of great interest. Since the neutron is an unstable particle with a mean life of about 19 min, most solar neutrons would decay before they reached the orbit of the Earth. A probe close to the Sun would therefore have a better chance of detecting them. Since, unlike charged particles, solar neutrons would not be influenced by solar or interplanetary magnetic fields, time correlation of solar neutron fluxes with solar-charged particle fluxes would give interesting information on the propagation of the charged particles, and therefore, on the structure of the solar and interplanetary fields themselves.

As an additional bonus, the recommended neutron-detection instrument is capable of detecting gamma rays as well. It is quite possible that crustal differentiation has occurred on Venus and perhaps on Mercury, thus producing a higher gamma-ray count than would normally be observed from undifferentiated, e.g., chondritic, bodies. In the case of Venus, the dense clouds would likely act as an effective shield against detecting from a flyby spacecraft any surface gamma radiation. Mercury seems to have no such shielding atmosphere, and a flyby distance of approximately 5000 km from the surface could provide some interesting scientific information.

V. Science Objectives and Typical Experiments

A. Objectives

The primary objectives of planetary science are the understanding of:

(1) Origin and evolution of life

(2) Origin and evolution of the solar system

(3) Physical processes that determine the terrestrial environment

For this particular mission, it is believed that experiments relating to objectives (2) and (3) above should have the highest priority. Thus, although Venus cannot be ruled out as an abode for life, the most practical scientific experiments for this mission would be those investigating the composition, pressure, temperature, and structure of the Cytherean atmosphere and nature of the surface. Information of this type is relevant to the biological problem, while at the same time, it can provide the fundamental information toward a better understanding of cosmogony and terrestrial problems. Investigation of Mercury should provide information for a better understanding of the atmosphere and surface of the planet, and its mass-density. The latter is particularly relevant to certain facets of the cosmogonical problem and a solution seems practical from the mission.

In the following pages, several specific scientific objectives that can be achieved on a mission of this type, and the corresponding scientific experiments or instruments to satisfy these objectives are presented. As indicated earlier, the mission profile can be either a Venus/Mercury flyby or Venus/Mercury flyby with Venus capsule, thus requiring a division of scientific payload between flyby science and capsule science. Section V-B and Table 1 present typical flyby science for a Venus/Mercury swingby mission; Section V-C discusses the flyby-capsule mix mission; Table 2 presents typical Venus capsule science, and Table 3 presents select flyby experiments for a so-called minimum flyby-capsule mission.

B. Flyby Science

An effort has been made to select preferentially those scientific instruments that can provide meaningful experimental information from both Venus and Mercury, or that take special advantage of this particular mission. Also, because this mission presents an unusual opportunity to investigate the interplanetary environment in

Table 1. Typical flyby experiments

Experiment	Venus science objectives	Mercury science objectives	Weight, lb	Power, w
1. Photo-imaging experiment	Provide information about nature and structure of a Cytherean atmosphere similar to data from early U.S. weather satellites for Earth.	Provide TV pictures of planetary surface to a resolution of about 150 m/TV line. Photograph entire visible disk of planet to obtain diameter and from this information, in conjunction with mass from trajectory, obtain an order of magnitude density determination.	47.0	20.0
2. Microwave spectrometer (multifrequency instrument)	Obtain limb-to-limb brightness temperature at several wavelengths from 3 mm to 3 cm. From these data, attempt to obtain information about the composition, the three-dimensional physical and thermal structure, the circulation, the density, etc., of the atmosphere.	Obtain a three-dimensional thermal map of planet surface/subsurface; also at shorter wavelengths one would hope to get information on temperature, pressure, and density of the planetary atmosphere.	35.0	10.0
3. Ultraviolet spectrometer	Determine abundance and distribution of upper atmospheric constituents, obtained from UV spectra of Venus.	Determine abundance and distribution of upper atmospheric constituents, obtained from UV spectra of Mercury.	30.0	12.0
4. RF occultation	Measure changes at several frequencies of spacecraft radio signal resulting from occultation of spacecraft by Venus and perhaps Mercury and the Sun. Give atmospheric scale heights for Venus and Mecury and planetary diameter for Mercury.		Part of spacecraft equipment for single experiment. Perhaps needs 6 lb for two additional frequencies.	
5. Relativity experiment	Measure change in range signal between space probe and Earth resulting from relativistic effect when range signal passes near the Sun.		N/A	N/A
6. Magnetometer	Investigate planetary and interplanetary magnetic fields, their relationship, characteristics, magnitude, direction and orientation.		7.2	5.0
7. Solar plasma	Make detailed energy and flux measurement, similar to OGO-E plasma experiment.		15.0	5.0 to 10.0
8. Trapped radiation detector	Determine intensity, direction and spatial distribution of planetary trapped radiation and interplanetary cosmic rays.		2.6	0.7
9. Micrometeoroid experiment	Measure flux of cosmic dust particles as a function of direction, distance from Sun, and momentum with respect to spacecraft.		10.0	0.5
10. Particle flux/ion chamber	Monitor total ionizing radiation, energy, and particle type with time and position in interplanetary space.		2.5	0.35
11. Cosmic ray and solar-charged particle telescope	Measure ion energy and spectra of cosmic rays and solar-charged particles.		8.0	0.4
12. Planetary mass	Determine mass of Venus.	Determine mass of Mercury.	N/A	N/A
13. Topside sounder	Detect low frequency spherics and radio emission that may contribute to microwave brightness temperature. Study properties of the ionosphere. May give altitude.	Study properties of the ionosphere.	10.0	5.0
14. Bi-static radar	Investigate surface characteristics and the diameter of the planet.	Investigate surface characteristics and the diameter of the planet.	5–10 depending on flyby distance	5.0
15. Low energy proton telescope	Measure the energy spectrum of low energy solar protons.		12.0	1.0
16. Fast neutron and gamma ray detector	Measure the energy spectrum of fast neutrons and gamma rays. Gamma ray data for Mercury could show the degree of concentration of radiative material in the crustal rocks.		10.0	1.5

Table 1 (contd)

Experiment	Venus science objectives	Mercury science objectives	Weight, lb	Power, w
17. Microwave spectrometer (surface imager)	Obtain a thermal map of a traverse of the Venusian surface of a wavelength longer than 3 cm. From these data, one would hope to get information on planetary thermal abnormalities, and an estimate of surface composition and structure.	Obtain a thermal map of a traverse of the planet's surface at one wavelength. From these data one would hope to interpret the thermal and electrical properties of the planetary surface in terms of geological processes, structure, etc.	25.0	10.0
18. Microwave spectrometer (combined multi-frequency instrument and surface imager)	Obtain limb-to-limb brightness temperature at several wavelengths from 3 mm to 3 cm. From these data, attempt to obtain information about the composition, the three-dimensional physical and thermal structure, the circulation, the density, etc., of the atmosphere.	Obtain a three-dimensional thermal map of planet surface/subsurface; also at shorter wavelengths one would hope to get information on temperature, pressure, density of the planetary atmosphere.	50.0	40.0

Table 2. Typical Venus capsule instruments

Instrument	Measurement capabilities	Approximate weight	Approximate power	Bits/sample and total information (Venus)[a]
Aerometeorometer	Static temperature: 180–800° accuracy of measurement is ±1% of ambient temperature.	10 oz	70 mw	9 bits/sample measurement every 500 m.
	Static pressure: 10 mb to 100 atmosphere. The accuracy of measurement is approximately 2%.	10 oz	100 mw	15 bits/sample measurement every 500 m.
	Density: 2×10^{-4} to 30 Kg/m^3, accuracy of measurement is ±1% of ambient.	15 oz	250 mw	10 bits/sample measurement every 500 m.
	Velocity of sound: 250 to 380 m/sec; 1% of ambient (accuracy of measurement).	10 oz	300 mw	10 bits/sample measurement every 500 m.
Mass spectrometer	Determine the composition of the atmosphere in the mass range of 12 to 50 amu.	5 lb	6.0 w	Desire at least 5 spectra—500 bits/spectra.
Visual or UV photometer	Determine the cloud tops and cloud base and the optical properties of the Cytherean atmosphere.	2 lb	1.0 w	7 bits/sample measurement every 500 m.
Impactometer	Distinguish between a hard and a soft surface; e.g., unconsolidated sand-like material and any consolidated surface.	3 lb	1.0 w	2-μsec pulses on the capsule carrier frequency.
Three-axis accelerometer	Provide data for determining pressure-density-RT product as a function of altitude.	3 lb (including 3500-bit storage unit)	1.0 w	27 bits per sample; sample every sec during supersonic flight and every 500 m during subsonic flight.

[a] Those instrument sampling rates which are stated in terms of altitude increments are not intended to imply variable sampling rates with respect to time. But rather, they imply average sampling rates which may be fixed after typical capsule descent profiles are known.

close to the Sun, and maybe over a time period coincident with solar maximum, a considerable portion of the scientific payload has been allocated to these experiments. Attempts to design a good scientific payload for a combined Venus/Mercury flyby mission are confounded by the fact that one planet has an extensive atmosphere; the other has almost no atmosphere at all, and further, the trajectory offers a very close flyby distance for Venus but a more distant one for Mercury. The task is quite feasible, however, as shown in Table 1.

A close Venus flyby miss-distance is preferred for the ultraviolet, microwave, magnetometer, trapped radiation, occultation, and such experiments. However, the photo-

Table 3. Flyby experiments for minimum flyby-capsule mission

Experiments	Venus scientific objectives	Mercury scientific objectives	Weight, lb	Power, w
1. Photo-imaging experiment	Will provide information about nature and structure of Cytherean atmosphere similar to data from early U.S. weather satellites for Earth.	TV pictures of planetary surface to a resolution of about 150 m/TV line. Photograph entire visible disk of planet to obtain diameter and from this information, in conjunction with mass from trajectory, get an order of magnitude density determination.	15.0	20.0
2. Microwave radiometer	Obtain the limb-to-limb brightness temperature at a wavelength of 3 cm.	Obtain a thermal map of the planet surface.	25.0	10.0
3. RF occultation	Atmospheric scale heights.	Atmospheric scale heights and planetary diameter.	N/A	N/A
4. Micrometeoroid detector	Measure local dust density.	Measure local dust density.	2.5	0.2
5. Relativity experiment	Measure changes in range signal between space probe and Earth resulting from relativistic effect when range signal passes near the Sun		N/A	N/A
6. Planetary mass	Determine mass of Venus.	Determine mass of Mercury.	N/A	N/A
7. Magnetometer	Investigate planetary and interplanetary magnetic fields.		5.0	5.0
8. Solar plasma probe	Measure quantity rate and energy of the positive ion solar wind.		5.0	2.0
9. Trapped radiation detector	Determine intensity, direction and spatial distribution of planetary trapped radiation and interplanetary cosmic rays.		2.5	0.7
10. Particle flux/ion chamber	Monitor the total ionizing radiation including energy and particle type with time and position.		2.5	0.5
11. Radio noise detector (topside sounder)	Observe low frequency spherics and radio emission that may contribute to microwave brightness temperature, and study properties of the ionosphere. Topside sounder can likely be modified to give altitude.	Measure electron density of the ionosphere.	2.5 to 10.0	5.0

imaging experiment, because it is optimized for a greater Mercury flyby miss-distance, would provide limited but high resolution area coverage of Venus from close into the planet. From a consideration of the probable trajectory, and of the resolution versus areal coverage versus scientific objectives for each of the experiments, a Venus flyby miss-distance of 5000 km seems practicable for this mission; however, a miss-distance of up to 10,000 km would be satisfactory.

For Mercury, a flyby miss-distance of 5000 km is considered optimum, but a miss-distance of up to 40,000 km would be satisfactory. The selected Mercury flyby distance and trajectory must offer a good opportunity to determine the mass of the planet. This is a most important scientific objective of the mission. Also, the desirability of a Mercury occultation experiment should be noted. It is expected that the wide dispersion of flyby distance quoted above will be compatible with several Venus/Mercury swingby opportunities for the period extending through the 1970s.

Muhleman (Ref. 48) has suggested the possibility that Einstein's Theory of Gravitation may be tested by measuring the range between the Earth and a space probe when the range signal passes near the Sun. The interaction effect is similar to the bending of starlight by the solar gravitational field. This is a fundamental experiment of great interest to the scientific community.

A necessary and important element of the science subsystem is the Data Automation System (DAS). In addition to those data management and control functions for which the DAS is responsible, a unique opportunity for an additional, "experimental" DAS responsibility may present itself for this mission. This would be a combined experiment in data compression and error detection coding. If the available S/C realtime telecommunication bit rate during the planetary encounter periods, each of approximately 6 hr duration, is sufficiently higher than is normally required, any extra bit rate may be used for this "data experiment." The realtime data from an instrument such as the UV spectrometer would, in addition to its normal processing, be compressed, encoded, and transmitted in real time. The decoded compressed data subsequently would be coupled, on Earth, to the corresponding "true" instrument data for an evaluation of the data compression technique. This experiment would require approximately 1 lb and 1 w.

*1. **Photo-imaging experiment.*** In the Venus-Mercury mission, the prime objective of the photo-imaging experiment will be photographs of Mercury, with photographs of Venus considered secondary in importance. The instrument will be designed accordingly.

It is expected that the appearance of Mercury on a kilometer scale will bear some resemblance to the appearance of the Moon and Mars. Thus, photography of Mercury will enhance our understanding of processes at work in the evolution of the surfaces of the Moon and Mars, as well as planetary bodies in general. Mercury is particularly interesting in this respect because of its extreme surface temperatures and temperature variations. The important objectives to be realized through photography are determination of the surface morphology and the relative appearance of the surface with respect to those of the Moon and Mars, and determination of the diameter of the planet.

The photo-imaging experiment on the Venus portion of the mission will yield new information about the nature and structure of the Cytherean atmosphere. Meteorological information similar to that obtained by U.S. weather satellites, with a resolution of 1 km or better, depending on flyby distance, will be obtained.

The specific experiment objectives will be as follows:

(1) Perform photographic reconnaissance sampling of the surface of Mercury at resolutions ranging from 750 to 150 m/TV line, or better, at closest approach.

(2) Photograph the entire visible Mercurian disk at a normal resolution of 10 km/TV line, or better.

(3) Map at least half of the illuminated part of the surface of Mercury at resolutions ranging from 7 to 1.5 km/TV line, or better, at closest approach.

(4) Photographically sample parts of the surface of Mercury in two or more wavelength bands in the visual and near-visual spectrum.

(5) Measure the diameter of Mercury. This information along with an accurate mass determination from the trajectory will give a more reliable figure for the mean density.

(6) Photograph portions of the Cytherean surface or cloud cover, including both terminator and limb, with about 2 km/TV line resolution in a sequential series in near-UV and yellow light. Pictures of 200 m/TV line, with limited spectral and areal coverage could also be obtained, and low-resolution pictures of the full disk, in near-UV and yellow light, could be obtained a few hours after the Cytherean encounter.

(7) Obtain information on the reflecting properties, relative albedo and photometric function, of both Venus and Mercury. For the latter, it would be very desirable for the spacecraft to pass directly between Mercury and the Sun.

The instrumentation will consist of two bore-sighted cameras of evolved *Mariner* design mounted on a scan platform having 2 deg of freedom. The anticipated video storage capacity requirement will be 2×10^{8} bits. The following are indicative of the type of system planned:

(1) Camera type: Advanced *Mariner*

(2) Weight: Camera A—16 lb total (8 lb on scan platform)
Camera B—31 lb total (23 lb on scan platform)

(3) Volume: Camera A—$8 \times 6 \times 6$ in. on scan platform
Camera B—$24 \times 9 \times 9$ in. on scan platform
$6 \times 6 \times 10$ in. on bus

(4) Power consumption: 32 w average

(5) Operation: Camera A and B pictures taken alternately, with a shuttered exposure about every 40 sec during operation

(6) Auxiliary equipment required:
  (a) Digital tape recorder (2×10^{8} bits)
  (b) Two-degrees-of-freedom mechanical platform
  (c) Planet center of brightness sensor and/or programmed pointing control

(7) Data rate: approximately 10^{2} bps to tape recorder

The design as now envisioned would not permit, without degradation, such a wide range in Mercury miss-distances as 5000 to 40,000 km. The resolutions and coverages suggested above are based on a miss-distance at Mercury of 5000 km with the TV subsystem parameters the same as those now planned for *Mariner 1969*. Changes in the optical subsystem could be made which would give the same resolutions and coverage at some other design miss-distance, e.g., 10,000 km, but once the design is fixed, variations in miss-distance greater than −50% or +100% would seriously degrade the photo-imaging experiment returns.

2. *Microwave experiment*

a. Venus. The planet Venus is of extreme interest in the microwave region since its optically thick cloud seems to be penetrable only by microwaves. Active microwave (radar) observations are suited for surface reflectivity measurements and surface imaging; passive (radiometric) observations are ideal for the study of surface emissivity and surface thermal mapping, as well as atmospheric characteristics.

In the passive microwave area, the following specific scientific objectives for spacecraft experiments can be listed for a lightweight flyby mission:

Atmosphere brightness temperature distribution. The limb-to-limb brightness temperature distribution of the Venusian atmosphere could be obtained at several wavelengths in the region of 3 mm to 3 cm. From Earth-based measurements, it has been well established that the brightness temperature integrated over the disk of the planet varies from approximately 350°K at 3 mm to approximately 575°K at 3 cm. The transition curve is irregular, appears to include emission lines, seems to fluctuate as a function of time; and, in general, is thought to result entirely from the complex atmosphere of Venus. The shorter wavelengths are thought to originate from the top of the atmosphere, the longer ones from successively deeper layers. By obtaining limb-to-limb brightness temperature scans over a large portion of the planet at the high resolution obtainable from a spacecraft, information such as limb darkening, geographical distribution, phase angle effects, polarization, and Brewster angle phenomena could be measured. Data of these kinds are extremely difficult, if not impossible, to gather from Earth due to the lack of a real resolution. The information would yield considerable detail about the composition, the three-dimensional physical and thermal structure, the circulation, the density, etc., of the atmosphere.

Thermal map of the Venusian surface. A thermal map or image, made at a wavelength longer than 3 cm to ensure penetration to the surface, would permit isolation of surface features such as mountains, plains, and continents, and would identify thermal abnormalities such as fault lines and volcanoes. Also, the maps would yield estimates of gross surface composition and structure.

Both of the above scientific objectives are best met if the flyby distance is in the order of 1000 km from the surface of the planet. At this distance, the areal resolution of instruments suitable for a light spacecraft would be in the order of kilometers to tens of kilometers, depending on the wavelength. The closer one passes to the surface (the higher the resolution, but the poorer the coverage); farther out, the inverse situation is true to a certain point. Useful information, however, could be obtained as far as 100,000 km from Venus. A final flyby distance specification needs further study.

b. Mercury. Very few microwave brightness temperature measurements have been made of Mercury to date. These range from 200 to 400°K. Virtually no phase effect is evident.[3] The possible error in all of these measurements is very large, however. This is due mainly to the small angular separation of the extremely hot Sun and of the planet. This results in pick-up of confusing solar energy in the sidelobes of the observing radio telescopes. A spacecraft-borne radiometer would be ideal to eliminate this problem and would also permit high areal resolution when moderately close to the planet. Also, a radiometer would make it possible to obtain a substantial portion of the total phase curve in very short time as the craft flies by.

The very thin atmosphere of Mercury would probably be undetectable by all but the shortest microwave wavelengths. The passive microwave measurements would therefore concentrate on mapping the surface and subsurface temperature of the planet.

The instrumentation for the Mercury flyby can be the same as for the Venus flyby provided that dual purpose of the instrument is pursued from the very beginning of the implementation. The following specific objectives would be achieved:

Surface and subsurface temperature distribution. An instrument scanning the surface of the planet from limb-to-limb at several wavelengths between 3 cm and 3 mm would obtain a three-dimensional temperature distribution of the planet crust because different wavelengths penetrate to different depths. Theory and measurements show that at 3 cm the penetration is in the order of meters to tens of meters in dry sand, or in this case, that the measured radiation represents the integrated emission from all the material down to this distance. The penetration is, of course, a function of the thermal and

[3] See Section III of this Report.

electromagnetic properties of the material. Shorter wavelengths have correspondingly less penetration, allowing the construction of "isotherms" by the use of the multiple wavelength instrumentation and subtraction of the various layer contributions.

The thermal maps will be interpreted in terms of geomorphology, thermal properties, and electro-magnetic properties of Mercury's crust. The fact that Mercury may rotate with respect to the Sun, and that the surface thus has a sinusoidal thermal input in time greatly facilitates the study of the surface and subsurface materials through differential thermal time constants.

As the spacecraft swings around the planet, valuable information about the phase effect, and hence the overall thermal regime of the planet, will also be obtained.

Depending on the composition of Mercury's atmosphere, there is a possibility that some information, such as atmospheric temperature profile and density, could be obtained at the shortest (~3 mm) wavelength in addition to the above data.

Thermal map of the surface of Mercury. This would be a much finer and complete coverage of the planetary surface than the above experiments. The measurements, however, would be at a single wavelength and thus would allow only two-dimensional analysis of the thermal and electromagnetic properties of the surface.

For both of the above experiments, the ideal flyby distance is in the order of 5,000 km. However, useful information could be obtained as far as 100,000 km from Mercury.

c. Scientific instruments

Multifrequency instrument. An instrument for the study of the atmosphere of Venus and the surface/subsurface of Mercury. At 3 mm, this instrument could give information on Mercury's atmosphere. The instrument characteristics are as follows:

Wavelengths:	2 to 4 wavelengths between 3 cm and 3 mm	
Weight:	35 lb	
Volume:	3 ft × 3 ft × 2 in. square antenna	= 1.5 ft³
	2 ft × 1 ft × 9 in. electronics	= 1.5 ft³
	Total	3.0 ft³
Power:	cruise — none	
	encounter — 30 w average	
Data rate:	30 bps approximately	
Other requirements:	planetary sensing/scan platform to scan whole radiometer at 1 deg/sec from limb to limb and 5 deg beyond each limb. Pointing accuracy not critical (±1°).	

Surface imager (Experiment 17). A single frequency instrument for surface/subsurface imagery on both planets. The instrument characteristics are as follows:

Wavelength:	3 or 4 cm	
Weight	25 lb	
Volume:	3 ft × 3 ft × 2 in. square antenna	= 1.5 ft³
	1 ft × 1 ft × 9 in. electronics	= 0.8 ft³
	Total	2.3 ft³
Power:	cruise — none	
	encounter — 10 w average	
Other requirements:	planetary sensor to orient antenna along local vertical; pointing accuracy needed: (±1°). Instrument scans electronically.	

Combination multifrequency sensor and surface imager (Experiment 18). The instrument characteristics from the Surface Imager and Combination Multifrequency Sensor and Surface Imager above, are as follows:

Wavelength:	multiple between 3 mm and 3 cm	
Weight:	50 lb	
Volume:	3 ft × 3 ft × 3 in. square antenna	= 2.3 ft³
	2 ft × 2 ft × 9 in. electronics	= 3.0 ft³
	Total	5.3 ft³
Power:	cruise — none	
	encounter — 40 w average	
Data rate:	60 bps approximately	
Other requirements:	planetary sensing/scan platform to scan whole instrument at about 4 deg/sec.	

3. *Ultraviolet spectroscopy*

The ultraviolet spectroscopy (Ref. 49) of a planetary atmosphere is concerned with the phenomena that occur when the atmosphere is subjected to radiation from the Sun. Atoms that are in the upper atmosphere may undergo resonance reradiation when the solar radiation contains resonance lines of the same atoms. Upper atmosphere molecules may fluoresce when the solar continuum at appropriate wavelengths penetrates to the level in the atmosphere where the molecules are present. The molecules absorb energy at several wavelengths and then reradiate at either the same or longer wavelengths. Solar radiation at all wavelengths in the ultraviolet undergoes Rayleigh scattering by the molecules in the atmosphere. The resulting spectrum contains spectral features of the incident solar radiation as well as absorption features that are produced by molecules in the planetary atmosphere. The ionization of atmospheric molecules by extreme ultraviolet solar radiation produces fast photoelectrons in the upper atmosphere. These photoelectrons may strike other atmospheric atoms or molecules and cause them to radiate.

Radiation from the Sun, in the broader definition of including charged particles and magnetohydrodynamic plasma waves, directly or indirectly causes the upper atmosphere to be subjected to charged particle bombardment at large geomagnetic latitudes. The electron bombardment during an aurora causes the atoms and molecules of the upper atmosphere to radiate.

The dayglow consists of the upper atmosphere emissions that occur when the atmosphere is directly illuminated by the Sun. The phenomena producing these discrete spectral features include resonance reradiation, fluorescence, photoelectron excitation, and chemical and ionic reactions. The spectral emissions of the aurora are produced by charged particle bombardment while the aurora itself is controlled in some way by the geomagnetic field. Historically, it has been observed at night when the daylight is absent; however, auroral emissions may be present during the daytime as well. The nightglow is produced by chemical and ionic reactions in the upper atmosphere and does not require the direct presence of solar radiation. The Sun is responsible, however, for the energy that appears in the nightglow spectral emissions. Finally, the twilight glow contains phenomena of both the dayglow and nightglow. It is the time when the lower atmosphere is in the shadow and both the fluorescence of the dayglow and the luminescence of the nightglow are present.

Table 4 gives some atoms that may undergo resonance reradiation in the atmospheres of Venus and Mercury, Table 5 shows those molecules that may undergo fluorescence, and Table 6 shows those molecules that may undergo absorption. It should be realized that solar

Table 4. Atoms that may undergo resonance reradiation in planetary atmosphere

Atom	Wavelength, Å
Argon	1048
Nitrogen	1200
Hydrogen	1216
Oxygen	1302, 4, 6
Carbon	1657

Table 5. Molecules that may undergo fluorescence in planetary atmosphere

Molecule	Wavelength, Å
Nitric oxide	2262
	1909
	2198
Oxygen	2026
	2885
Nitrogen	2010
	1450
	986
	3370
Hydroxyl	3064
Cyanogen	3876
Carbon monoxide	2063
	1544
	1804
Nitrogen ion	3911
	1549
Nitric oxide ion	1368
Oxygen ion	2610
Carbon monoxide ion	2191
	4900

Table 6. Molecules that may produce absorption in planetary atmosphere

Molecule	Wavelength, Å
Ozone	2000–3000
Oxygen	1250–1750
Carbon dioxide	1250–2000

ultraviolet radiation will dissociate many heavier molecules in the atmosphere of Mercury and that the lighter gases and dissociation products may easily escape, thus the only gas in the atmosphere may come from the interplanetary medium or be a product of the interaction of this medium with the surface.

The experiment constraints and instrument characteristics for the ultraviolet spectrometer for a Venus/Mercury flyby mission are as follows:

(1) It is desired that the measurements begin at approximately 10^5 km from both planets, the absolute distance to be established during spacecraft design.

(2) Straight line scan across both planets.

(3) In order to satisfy the requirement for spectral resolution, it is desired that the spacecraft pass within at least 5000 km of the surface of Venus, and as close as the trajectory will allow for Mercury. Instrument resolution is a function of flyby distance.

(4) Accurate aperture alignment at terminator crossing and sub-solar point tangential measurement.

(5) View shall not be obstructed by spacecraft within 4 deg cone about look axis.

(6) Field of view shall be 2.5 deg.

(7) Scan no closer than 10 deg to Sun-probe line.

(8) Weight and power will be approximately 30 lb and 12 w, respectively.

(9) Dimensions: 24 in. long $\times$ 8 in. $\times$ 9 in.

(10) Data rate will be as high as 3×10^3 bits per second in real time, or approximately 10^4 bits per spectrogram.

(11) Great care must be taken in instrument design to use a detector that will not be swamped by visible light reflected from the planet.

4. RF-occultation experiment. At a minimum, this would be the same experiment as flown on *Mariner IV*; it would measure changes in the spacecraft radio signal resulting from the effect of the Cytherean atmosphere during occultation. From these data, values for the atmospheric and ionospheric scale height, density, pressure, and temperature could be found. It would be desirable to extend this experiment by using several spacecraft frequencies for more resolution on the atmospheric parameters and perhaps a determination of the diameter of Venus. Depending on the trajectory this could be a valuable experiment on both Mercury and the solar corona. For Mercury this experiment should give both the atmospheric and ionospheric scale height, density, pressure, and temperature as well as the planetary diameter.

5. Relativity experiment. A mass as large as that of the Sun will modify the path of an electromagnetic wave that passes by it. It will produce an angular deflection of the wave and a time delay. The magnitude of both are predictable by the General Theory of Relativity. Thus, the General Theory can be given an additional test (the fourth) by measuring the time delay of an electromagnetic signal from a Sun occultation space probe to the Earth.

The probe would undergo range tracking for a considerable period before it occults the Sun. Its orbital range could then be predicted by Newtonian dynamics to a fraction of a kilometer. This is sufficient accuracy to enable the detection of a time delay in the signal due to the gravitational mass of the Sun.

The same data would also make it possible to measure the gravitational oblateness of the Sun. This bears an important relation to the third test of general relativity which is the predicted precession of the perihelion of the planet Mercury. A small oblateness of the Sun would account for an effect now attributed to general relativity.

No error analysis for the relativity experiment has been made for this mission, but it has been done for potential Venus and Mars flyby missions, and it appears to be feasible. Presumably then missions such as the one studied in this document could be utilized for this important experiment.

6. Magnetometer experiment. The selection of a magnetometer to carry out the experimental objectives should be relatively simple now that so much is known of the interplanetary medium and a bound has been established for the magnetic moment of Venus. Either a fluxgate or vector helium magnetometer would be adequate, especially if one takes into account the developments that are likely within the next few years. Conservative estimates of the maximum weight and power required to read-out the three orthogonal sensors are 5 lb and 4 w, respectively. Adequate bit rates are from 3 to 12 bps during cruise and from 15 to 30 bps during encounter. The major problem area would undoubtedly continue to be the contamination of measurements by spacecraft magnetic fields.

7. ***Solar-plasma experiment.*** The ideal instrument for making solar-plasma measurements in the vicinity of, and enroute to, Venus/Mercury would be similar to the OGO-E plasma probe, which incorporates both a spectrometer (electrostatic analyzer) for making detailed energy measurements and a Faraday cup probe for making flux and direction measurements. A revised design of this instrument has been proposed for *Voyager.* It weighs 15 lb, consumes 10 w if operated continuously, and occupies about 1.5 ft^3. It is capable of providing much better energy resolution, time resolution, and separation of hydrogen and helium solar-wind components than any plasma probe that has yet been flown. Adequate bit rates are from 1–4 bps during cruise and from 5–10 bps during encounter.

If weight and power are at a premium, a less versatile instrument could be used that would require about half the weight, power, and volume of the proposed *Voyager* instrument.

It should be noted that the magnetometer and plasma instruments can be operated in a joint fashion to form a useful solar flare detection and recording experiment. An Earth-Venus-Mercury trajectory provides an excellent opportunity for experimentally studying plasma fields related specifically to major solar flares. The opportunity is significantly enhanced by the presence on-board the spacecraft of a large capacity digital tape recorder which is idle during the extensive interplanetary cruise periods. The flare detection concept would require the use of an appropriate detector capable of responding to a major flare condition from monitoring the plasma probe output. Then, whenever a major flare is detected, high rate data from the plasma probe and magnetometer would be stored on tape for subsequent playback.

8. ***Trapped-radiation experiment.*** To accomplish the scientific objectives of the trapped-radiation experiment, instrumentation similar to that carried on *Mariner IV* would be quite satisfactory. The characteristics of these detectors are shown in Table 7.

Table 7. Characteristics of trapped radiation detectors

Detector	Charged particles detector	Remarks
213 GM counter	Protons > 500 Kev + Electrons > 40 Kev	Identical detectors are oriented in different directions to get directional information.
213 GM counter	Protons > 500 Kev + Electrons > 40 Kev	
213 GM counter	Protons > 900 Kev + Electrons > 70 Kev	
pn junction		
Lower discriminator:	Protons 500 Kev > E ≤ 8 Mev No electron sensitivity	
Upper discriminator:	Protons 900 Kev ≤ E ≤ 5.5 Mev No electron sensitivity	
Total weight		2.6 lb
Total power		0.6 w
Total volume		80 in.^{3}
Minimum bit rate		⅓ bit/sec average

9. ***Micrometeoroid experiment.*** It would be practical to use an instrument similar to that flown on *Mariner IV* but employing a sensor with several active faces. The scientific objectives of this experiment would be to:

(1) Measure the flux of cosmic dust particles in interplanetary space as a function of direction, distance from the Sun, and momentum with respect to the spacecraft.

(2) Determine the variation of cosmic dust flux with distance from the Earth, Venus, and Mercury.

(3) Investigate any concentration of cosmic dust in streams.

The instrumentation for this experiment would weigh 10 lb, use 0.5 w of power, and require a maximum data capability of 1 bps.

10. ***Particle flux/ion chamber.*** This experiment, the same as flown on *Mariner IV*, would measure the total ionizing radiation at the spacecraft position, provide semiquantitative information about the energy and particle types composing the radiation, and the variation of this radiation in time, distance from the Sun, and relative to terrestrial observations.

The instrumentation for making these measurements would consist of an integrating chamber and matching Geiger-Mueller counter. Both sensors will be shielded so as to detect protons with energy > 10 Mev, and electrons with energy > 0.5 Mev. The complete instrument package would weigh about 2.5 lb, use 0.35 w of power, and require a maximum data capability of 10 bps during periods of high activity. The weight-power data requirements for extending the range of this experiment would be very small.

*11. **Cosmic-ray and solar-charged particle telescope.*** A counter telescope similar to that flown in *Mariner IV* would give interesting scientific data on cosmic rays and solar charged particles. The instrument employs gold-silicon surface barrier, solid-state detectors in a telescope geometry. The basic parameters measured for particle identification are energy-loss, and particle range. The instrument is designed to measure protons and alpha particles, and to be immune to electron fluxes over a considerable range of intensity. The total payload weight is about 3 lb. The total raw power input is less than 0.4 w.

The proton intensity in the following energy ranges is measured:

1.0 to 10 Mev

10 to 80 Mev

80 to 200 Mev

The alpha particle intensity in the following energy ranges is measured:

3 to 10 Mev/nucleon

10 to 3 Mev/nucleon

80 to ∞ Mev/nucleon

The full cone of view for the telescope is 60 deg (30 deg half angle) which is not to include any part of the spacecraft or the Sun. Pulse rates for quiescent background fluxes in interplanetary space range from the order of 1 count per sec down to 0.3 counts per min.

*12. **Planetary mass.*** The current value for the mass of Venus was calculated from the effect of Venus on the orbit of *Mariner II*; so, in principle, this experiment has already been accomplished for Venus. In the case of Mercury, however, this is a very important experiment. The present mass of Mercury is in error by perhaps 10%. A flyby distance of 25,000 km could improve this to an uncertainty of less than a few tenths of 1%.

*13. **Topside sounder.*** The objective of this experiment is to make radio "soundings" of the ionosphere of Venus and Mercury by either a fixed or sweep-frequency technique in the frequency range of 1 to 15 Mc/s. The topside sounding frequencies for *Alouette* varied from 1 to 11.5 Mc/s. The experiment would give information on the vertical and horizontal distribution of electron densities; also, at the higher frequencies, or given low electron densities, as with little or no ionosphere, the topside sounder might be used to give information on the altitude of the spacecraft from the surface of the planet. The instrument could serve as a radio noise receiver in its frequency range.

A crossed dipole antenna measuring perhaps 50 ft in diameter would be required; however, unfurlable lightweight structures appear to be feasible. It may even be possible to utilize the solar panel structure for the antenna.

*14. **Bi-static radar.*** In a bi-static radar system, the transmitter and receiver are widely separated. In this particular case, the transmitter would be on Earth and the receiver would be on the flyby spacecraft. Depending on flyby distance the antenna receiver system for the Venus portion of the mission would weigh about 10 lb. The experimental objectives would be a determination of the planetary diameter from radar signal occultation plus some information on the surface radar characteristics that may be required for subsequent missions.

*15. **Low-energy proton telescope.*** Plasma detectors are not capable of detecting protons with energies greater than a few tens of kilovolts. The other radiation-detection instruments are not sensitive to protons of energy less than about 0.5 Mev. There is considerable interest in studying the energy spectrum of solar protons in this energy gap. A solid-state detector, scintillation counter telescope with very low-noise electronic amplifier, could be designed to cover the energy range from about 60 kev to 0.5 Mev and above. This system would weigh about 12 lb and consume 1 w of power.

*16. **Fast-neutron and gamma-ray detector.*** A modified *phoswich* type scintillation detector, with associated pulse height analyzer and electronic discriminators can be designed to detect neutrons from 1 to 15 Mev. It will also detect gamma rays from about 0.5 Mev to 4 Mev. Such an instrument would weigh about 10 lb and consume 1.5 w.

C. Flyby Mission Plus Venus Capsule

Nearly all of the constraints that were discussed for the flyby-only mission in the earlier section can be applied to the flyby-capsule mission; however, now the scientific payload must be divided between flyby science experiments that can provide meaningful information for both Venus and Mercury, and a Venus capsule. Also, the total capsule weight including the power supply, the heat shielding, the attitude stabilization if required, the retro-propulsion if required, and other required systems, must be included as a part of the science payload. For the 1360-lb spacecraft this mix mission would appear to be both feasible and very desirable in terms of adequate scientific return. A typical mix here could consist of the first 14 flyby experiments, discussed in the preceding Subsection B and listed in Table 1, plus the Venus capsule.

For the 1000-lb spacecraft, the mixed mission appears to be very marginal, for the total scientific payload must now be divided between flyby experiments that are meaningful for both Venus and Mercury, and the total weight of the Venus capsule. The absolute minimum flyby science payload is shown in Table 3 and consists of TV, X-band Radiometer, RF Occultation, Micrometeoroid Detector, Relativity Experiment, Planetary Mass, Magnetometer, Solar Plasma Probe, Trapped Radiation Detector, Particle Flux/Ion Chamber, and a Radio Noise Detector or Topside Sounder. The total weight is about 50 lb.

The capsule or drop sound can be instrumented to provide first-hand information on some of the environmental properties of the Cytherean atmosphere. The capsule, although not designed to survive the ballistic impact on the planet's surface, should carry some kind of impactometer to distinguish between solid and liquid surfaces. It is also desirable to include a method for determining the environmental measurements as a function of altitude. Instruments to accomplish this could vary from a lightweight and simple three-axis accelerometer technique, where the capsule altitude would be interpretive as a function of the deceleration curve, to techniques using radar for precision capsule-altitude measurements.

If additional weight, power, and data capabilities are available, then it would also be desirable to incorporate an atmospheric aerosols detector or disdrometer. An instrument commercially available through Bausch and Lomb used for counting dust particles ranging in size from 0.3 to 10μ at concentrations between 10^3 and 10^6 particles per cubic foot, may be suitably modified for this.

A suggested capsule scientific payload is shown in Table 2 and is discussed in the following paragraphs. It should consist of a Thermodynamic Variables package, which includes experiments to examine the density, temperature, pressure, and velocity of sound of the atmosphere; an atmospheric composition experiment; an impactometer; a visual or UV photometer to determine the cloud-layers and the scattering properties of the atmosphere, and a triaxial accelerometer. The total science payload weight is only about 17 lb.

In considering these capsule instruments, note that:

(1) In no case has the weight of the ducts or tubing been taken into consideration (assumed to be structure weight).

(2) It is desired that the capsule reach a velocity of Mach 1 as high above the planet's surface as possible, as the experiments were chosen for the subsonic regime of the descent.

(3) Attitude stabilization of the capsule is required (e.g., spin stabilization).

(4) The heat shield will be a source of error during the measurements due to the thermal energy it will have at the time, and due to unpredictable aerodynamic behavior subsequent to the loss of the ablative material. The shield should therefore be jettisoned or its effects on the instruments clearly understood.

(5) Digital conversion, buffering and specialized processing of the output data from these instruments will be performed by a capsule DAS.

(6) It is possible, because of the nature of the Cytherian atmosphere, that the capsule may survive the surface impact. If this should happen it would be desirable that the science subsystem be capable of providing postimpact data. The most important information would be of temperature, pressure and composition. For this the instruments themselves need not be changed; however, some technique such as multiple porting to forestall any possibility of the capsule settling on its only sensor input port should be considered. Also, multiple porting for the pressure transducer may give an indication of any surface winds if more than one port is in the wind stream.

1. Thermodynamic variables. Four instruments relating to pressure, density, temperature, and velocity of sound are suggested for the thermodynamic variable package. Each should have an analog output. Sterilization, if required, does not appear to be a problem with these instruments. It should be realized that a variety of instrumental techniques are possible for these experiments and the following is only one suggested approach. Capsule directional stability and a speed of less than Mach 1 are required for most of these instruments. The triaxial accelerometer, discussed later in this Report, will provide information towards a better understanding and interpretation of these experiments; also, the aerodynamic properties of the capsule as recorded in flight by the triaxial accelerometer will provide basic information about the atmospheric density-pressure-temperature during both the supersonic and subsonic portions of the flight. Thus, the atmospheric density could be interpreted as a function of capsule oscillation and velocity for the complete deceleration profile.

a. Density. The suggested instrument would use an absorption technique in which the energy loss between a Beta source and a detector would be measured over a known gas path. The Beta source should be of low intensity to avoid affecting the cruise science radiation experiments, and should be shielded. A one millicurie source seems reasonable. The instrument is expected to perform over a pressure range from 0.1 to 100 atm with a sensitivity of approximately 2×10^{-5} g/cc. The instrument will weigh less than 15 oz. A physical location adjacent to the capsule wall is desirable.

b. Temperature. A vortex tube or similar device to counteract the effect of speed on the temperature reading may be required. The device must be deployed in free stream or located at a static pressure point at the rear of the capsule and thus calibrated as a part of the total capsule system. A resistance type thermometer, or other temperature sensor, with a dynamic range from 100° to 800°K is required. This equipment would weigh about 10 oz.

c. Pressure. It is desirable to begin the pressure readings at as great an altitude as possible above the planetary surface and these data should proceed in a continuous profile to the surface. A sample interval of every 500 m would be satisfactory. The accuracy of the pressure reading should be about 2% of the ambient pressure with a response time of 0.5 sec. The instrument sensors will require a static pressure point and calibration as a part of the total capsule system. The proposed instrument package would consist of two sensors: an aneroid barometer for measuring the low pressures at the higher portions of the Cytherean atmosphere and a Statham type gauge for measuring the higher pressures that might prevail near the bottom of the atmosphere. The instrument package will weigh about 12 oz and measure 4 in. in diameter by 3 in. long.

d. Velocity of sound. The velocity of sound in the Cytherean Atmosphere will be a function of both the density and temperature of the atmospheric medium, and to a lesser extent the wind velocity; therefore, this experiment is expected to provide information that will be useful in the interpretation of the density and temperature experiments discussed above. It would really be desirable to conduct this experiment after the fashion of a so-called Grenade Experiment where the capsule would eject small charges at specified points in its traverse through the atmosphere, and the acoustical properties of the atmospheric medium between the individual point sources and the detector or geophone on the capsule could be determined. The weight, power and instrument sophistication for this type of experimental approach will not likely be possible on this mission, however. A simple lightweight practical experiment for determining the acoustical properties of the Cytherean Atmosphere could be composed from two acoustic detectors separated orthogonally from a point sound source. The detector-source spread should be at least 5 cm, and should be located where least affected by the airflow about the capsule. A short boom position would be best. If this is practical, then the experiment may even give some information on the atmospheric wind velocity.

A minimum experiment is listed in Table 2. It would consist of an acoustic source and one detector to be separated by a distance of 5 cm. The time of travel between the source and detector would be measured. The experiment would weigh about 10 oz, not including the boom or pickup point.

2. Atmospheric composition. Atmospheric composition can be determined by either a mass spectrometer, gas chromatograph, or a series of simple composition instruments. The elements and compounds of major interest are: H_2O, O_2, A, N_2, CO_2, hydrocarbons, and O_3.

In the case of O_2, A, the hydrocarbons, and O_3, it would be desirable to know the percentage or amount present to a few parts per million. For CO_2 and N_2, a 1% accuracy is sufficient.

A 60-deg magnetic sector mass spectrometer could be considered for this experiment. This instrument is presently in breadboard stage; it uses a permanent magnet weighing about 2 lb. It has a dynamic range of 10^5, which would allow 0.01% components to be measured if one assumes a factor of 10 padding in the Venus atmospheric pressure estimate. Gaseous constituents within the mass range of 12–50 amu will be detectable. A few of these are: CH_4, H_2O, Ne, N_2, O_2, Ar, and CO_2.

All of these constituents can be determined in the present system down to 0.1% by volume. The present input pressure sampling limit of the system without special purging is 0.5 atm or less; however, a Bernoulli tube principle to exchange the sample in the examining chamber would be simple and weigh less than a pound. The mass spectrometer with the present all-solid-state electrometer can maintain its dynamic range with a 60-sec scan between masses 12 and 50. If the dynamic range were reduced to 10^4, a single scan could be made in 2 sec.

The number of data bits required by this experiment is difficult to assess without specific telemetry ground rules. Complete spectra could require several thousand bits. Utilizing peak detection methods, one could determine the absolute partial pressures of the major components for about 500 bits per spectrum.

3. ***Visual and/or UV photometer.*** The purpose of this experiment is to determine the altitude of the cloud tops and look for a layered structure in the Cytherean Atmosphere that would indicate separate cloud decks. This information will be interesting in terms of the experiments discussed above.

This instrument will weigh approximately 2 lb, incorporating a look direction back along the trajectory, and it should begin to operate before Mach 1 or at a pressure-altitude of approximately 10 mb. It should have a sensitivity to most of the visible spectrum, e.g., 4000 to 6000 Å. If additional weight, power, and data rate are available, it would be desirable to include a narrow band sensor tuned for about 3000 Å to examine the scattering properties of the atmosphere.

4. ***Impactometer.*** A device to indicate the hardness/density of the Cytherean surface from the ballistic impact of the capsule is very desirable. Instrumentation to perform this measurement is limited by capsule weight, power, data rate, and finally, by destruction upon impact.

The suggested experiment is an impact accelerometer designed to provide an order-of-magnitude measurement of the hardness/density of the surface into which it impacts by indicating the rate of change of velocity measured between the discharge of one electrode in the outer skin of the capsule and a second electrode in the inner skin of the capsule. The capsule would be acting as a hollow shell-type accelerometer.

At impact, the outer electrode begins to collapse or flatten out. The inner electrode, not physically connected to the outer shell, feels no forces, hence continues forward with its velocity unchanged. If the target surface is completely unyielding, as is nearly the case with solid rock, the outside capsule surface will flatten on the impact surface, and the original distance between the two electrodes will close at the impact velocity. If, on the other hand, the impact surface is of very low density, or yielding such as water, the flattening of the outer surface and the time between pulses from the discharge of each electrode will be longer. The entire capsule may be destroyed upon impact, or a few microseconds after the impact accelerometer had passed its two pulses to the capsule transmitter. If the capsule is instantly destroyed upon impact, neither pulse from the impactometer can be reliably transmitted; however, even under these circumstances, the impactometer would provide useful data of an impact time reference. This time reference would also be important in the case where the capsule is not destroyed upon impact and telemetry continues.

5. ***Three-axis accelerometer.*** This instrument will be an integral part of the complete capsule system. It is expected to provide:

(1) The primary science data for the supersonic portion of the capsule flight

(2) Information that will be useful in the interpretation of the other capsule instruments

For the supersonic portion of the flight, known aerodynamic properties of the capsule will cause it to react to the Cytherean Atmosphere by deceleration and oscillation, thus providing information interpretive in terms of atmospheric density-pressure-temperature. For the subsonic portion of the flight, and down to the terminal velocity point, the 3-axis accelerometer will provide information interpretive in terms of atmospheric density-pressure-temperature, and also, relative altitude information that will be useful for interpreting the data from the other capsule science instruments.

During the supersonic entry portion of the capsule descent, an ionization sheath will likely form to interfere with communications; therefore, data storage capabilities will be required to preserve these data for later transmission. The data rate for the 3-axis accelerometer will be less than 27 bps and the sample interval during the high speed portion of the flight should be every second if possible to a total recorder capacity of 3500 bits, or two min. The total duration of the supersonic portion of the flight will be a function of entry velocity, entry angle, atmospheric density, capsule shape, capsule density, and other considerations, and therefore, is unknown at this time. If the supersonic portion of the flight is expected to last for longer than the data storage capabilities of the recorder, then a two second sample interval is recommended or data logic be used to control the sampling rate.

During the subsonic portion of the descent, the 3-axis accelerometer should be sampled every 500 m, or as frequently as the data link will allow. This experiment including the data buffer will weigh approximately 3 lb.

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